AEDC

Space Environment Simulation Capabilities

Arnold Engineering Development Center

An Air Force Materiel Command Test Center

TEST HIGHLIGHTS

ON THE COVER:
Top Left: Installation of 7V Chamber Optical Bench
Top Right: Artist's Rendering of Mark I Space Chamber
Bottom Left: Aerospace Chamber 10V
Bottom Right: Aerospace Chamber 12V

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CATEGORY/EXPERTISE
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Aircraft Systems

AEDC/DOF -7721 -3339

- Aircraft/missile performance, stability, and control
- Propulsion/inlet integration and compatibility
- Store/stage separation
- Weapons carriage
- Aero-optics
- Signatures

Aeropropulsion Systems

AEDC/DOP -5305 -7205

- Performance, operability, observability, and specialized testing of turbine systems
- Environmental testing (temperatures, precipitation, and icing)

Space and Missile Systems

AEDC/DOS -6100 -3526

- Performance, operability, and observability of solid- and liquid-propellant rocket systems at altitude
- Sensor calibration and mission simulation
- Nuclear weapons effects
- Contamination
- Thermal vacuum
- Infrared signatures
- Space dynamics
- Aerothermal material
- Hypervelocity impact
- Ablation and erosion
- Wake physics
- Bird impact

Technology

AEDC/DOT -6523 -3559

- Develop new facility concepts and instrumentation
- Develop new test and analysis techniques

Electronic version of ***Test Highlights*** is available on the AEDC World Wide Web home page at http://www.arnold.af.mil.

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The Arnold Engineering Development Center (AEDC) is the world's most diverse complex of aerospace ground test facilities, with 58 aerodynamic and propulsion wind tunnels, rocket and turbine engine test cells, space environmental chambers, arc heaters, ballistic ranges, and other specialized units. AEDC is located in Middle Tennessee approximately equidistant from Nashville, Chattanooga, and Huntsville, Alabama, and is one of the Air Force Materiel Command's major test centers. Since its dedication in 1951, AEDC has been instrumental in the development of every major advance in flight technology and the space programs.

The AEDC mission is to provide high-quality, economical, and timely state-of-the-art test and evaluation (T&E) services in support of the U.S. Department of Defense (DoD), NASA, commercial, and international aerospace programs. In addition to this T&E mission, research and technology programs are conducted to develop advanced testing techniques and equipment; new facilities are designed and constructed; and the existing facilities are kept current through maintenance and modernization programs. We are committed to the continuing pursuit of our goal to satisfy our customers' needs in war and peace, enable our people to excel, sustain technological superiority, enhance excellence in our business practices, and operate quality test facilities.

The mission of the Space and Missile Systems Test Division at AEDC is to provide hypersonic, rocket propulsion, and space environmental T&E services. The Space and Missile Systems Test Division also maintains the nation's largest archives of rocket plume signature data at the Advanced Missile Signature Center (AMSC). The space environmental simulation test mission is highlighted in this document and includes sensor performance and mission simulation, radiation effects, and spacecraft thermal/vacuum environment and contamination effects.

Team Effort

Together, AEDC and the customer plan the T&E program and form agreed-upon expectations and organizational responsibilities for the effort. Support early in the program planning phase is advantageous to identify the proper approach for accomplishing program objectives at a minimum cost. A preliminary rough-order-of-magnitude (ROM) cost estimate may be provided during early planning, but a detailed review of the requirements is necessary to produce a final cost estimate. The detailed requirements study begins once the customer's funding is received and culminates in an AEDC Statement of Capability (SOC) containing security, safety, scope, objectives, schedule, and cost breakdown information. The SOC must be agreed upon and signed by the appropriate AEDC and customer representatives for further AEDC work to occur. Continued communication between AEDC and the customer is critical throughout the project to deliver maximum value and customer satisfaction. At the conclusion of each project or at least annually, we ask our customers to evaluate AEDC's cost, schedule, and technical performance against those agreed-upon expectations. The results are vital to AEDC and are used to continually improve team processes and develop capability investment strategies to improve future facility performance.

Arnold Engineering Development Center Arnold AFB, Tennessee

Space Environment Simulation Overview

Introduction

AEDC's space environmental test capabilities include a variety of facilities, support equipment, and expertise. The capabilities are highlighted accordingly:

- Sensor and Focal Plane Array (FPA) Characterization and Mission Simulation
- Radiation Effects Simulation
- Spacecraft Contamination Effects
- Thermal/Vacuum Environment Simulation
- Capability Investments

The space environmental simulation facilities are housed within two neighboring complexes as shown below. These facilities are supported by a substantial infrastructure which includes liquid nitrogen and gaseous and liquid helium supply systems, vacuum systems, computers, and diagnostics. In addition, capabilities include laboratory support equipment, modeling and simulation tools, and applied technologies research.

Aerial View of AEDC's Space Environment Simulation Complexes

Sensors

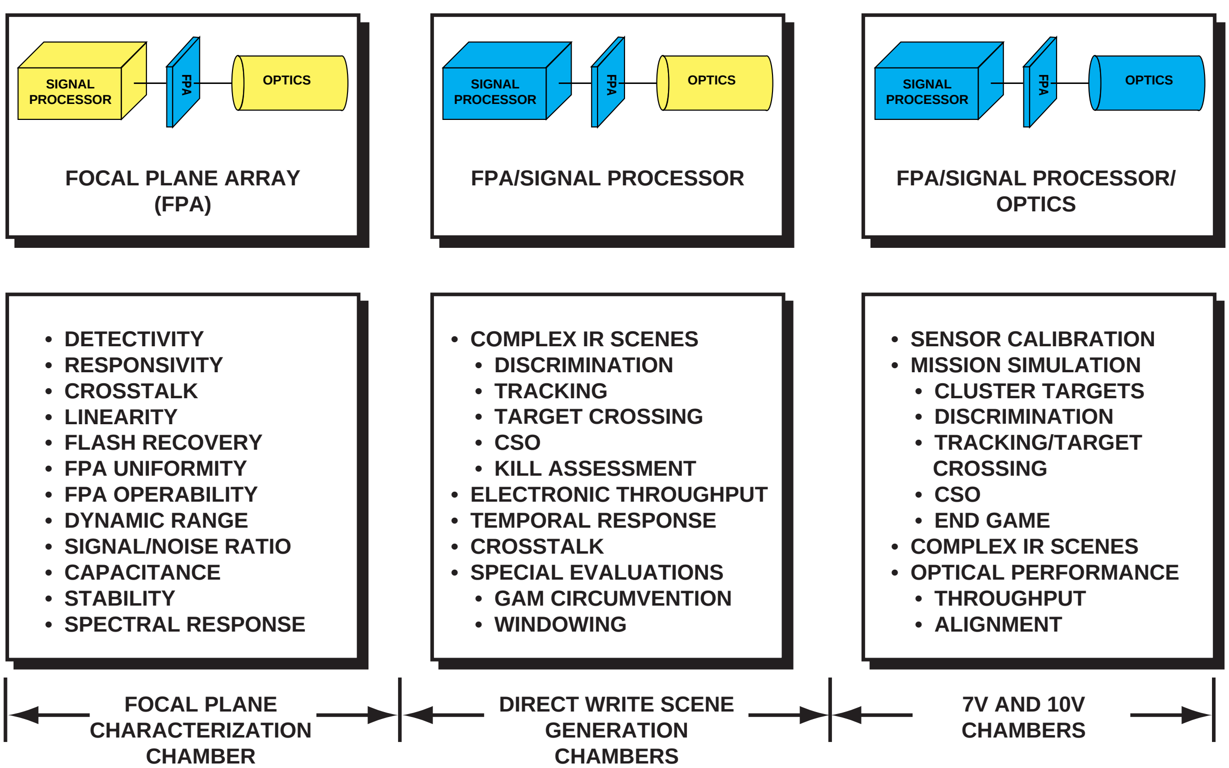
Information superiority and precision engagement weapons are keys to future war-fighting success. These requirements manifest themselves in strenuous specifications for current surveillance, tracking, and interceptor sensor systems in acquisition. The latest technologies must be inserted from research and development (R&D) for elements such as focal planes, electronics, and processing algorithms in order to meet the warfighters expectations. This forces an equally difficult set of requirements on the ground test and evaluation (T&E) assets that support these systems. Capabilities must exist to address validating models, development test and evaluation (DT&E), hardware in the loop, early operation test (OT), and production/qualification T&E. In response to those T&E requirements, AEDC recognized that a single test facility could not feasibly address the strategies laid out in the various program test plans without substantial program risk taking. AEDC developed a methodology and received funding to produce a suite of capabilities driven toward the more complex, high fidelity issues. These facilities complement in-house contractor assets in order to provide defense programs with a complete ground test capability with modern, up-to-date facilities. All of the sensor test facilities have been upgraded within the last five years to meet the needs of today's acquisition programs.

AEDC can test sensor systems at any level of development, from characterization of the Focal Plane Array (FPA) up to full-scale testing of the sensor. AEDC developed its sensor test facilities based on a test methodology that supports the three primary stages of a sensor's development: first the FPA is characterized, next the signal processor electronics are integrated with the FPA to characterize the effect the electronics have on the FPA's response, and finally the optics package (telescope) is added and the complete sensor system is tested.

The AEDC sensor test complex includes the Focal Plane Characterization Chamber (FPCC), the Radiometraic Calibration System (RCS), the Direct Write Scene Generator (DWSG) test lab, and the 7V Chamber. Future capabilities will include closed-loop ground-based operational T&E and combined nuclear weapon and mission band effects; these capabilities are planned for completion by year 2003.

Focal Plane Test Capabilities

The typical flow of testing for a hybrid FPA at AEDC is shown on page 5. The steps in the char-



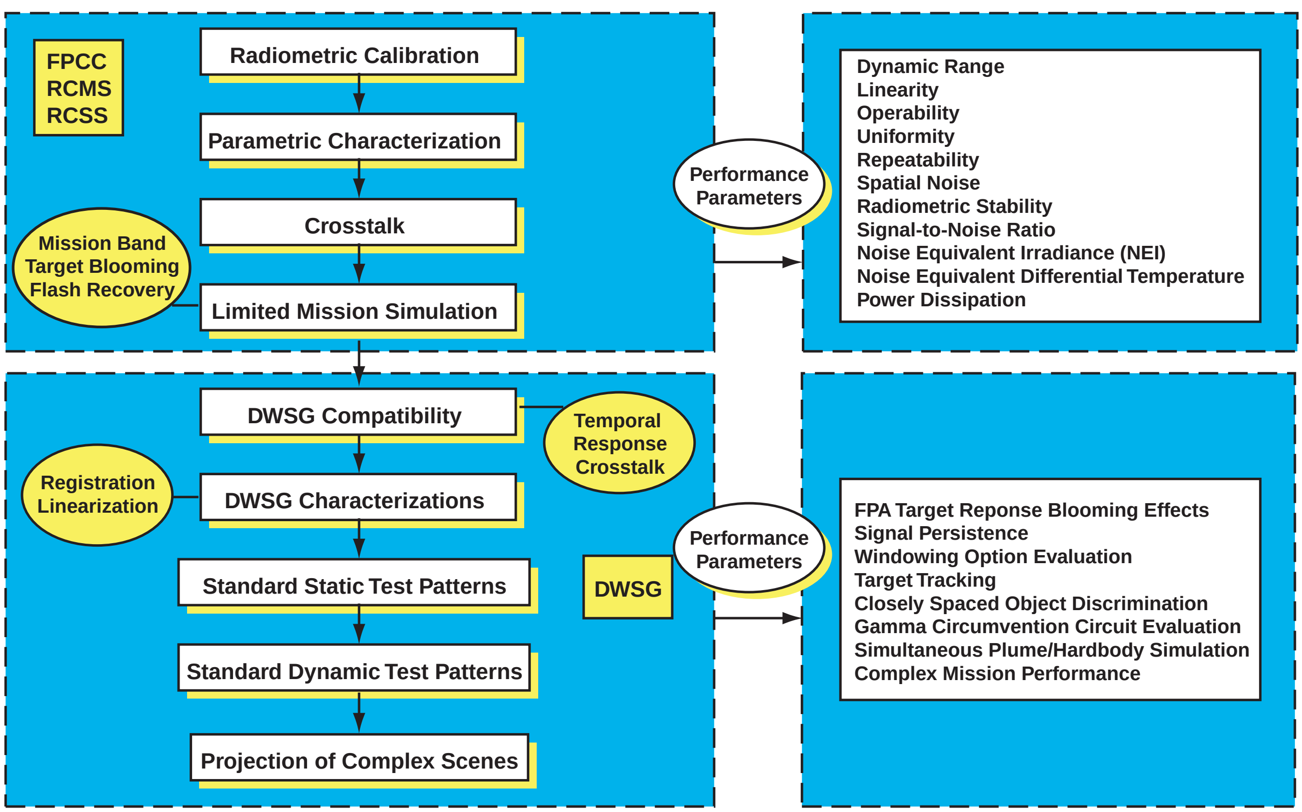
AEDC Sensor Test Philosophy

acterization process are listed on the left side of the chart. The corresponding issues or performance parameters are listed on the right side. The issues addressed by the two major classes of test facilities are indicated by the breaks in the two columns. The primary radiometric characterization facilities include the FPCC and the RCS. Both contain a variable temperature blackbody with an aperture wheel and a spectral bandpass filter wheel. The RCS is portable and can be readily moved to the desired test site, while the FPCC is a stationary test cell. The RCS is primarily used to provide characterization of FPA response as a function of target flux; this characterization is required to support testing with the DWSG system. A separate test station based around a 3-grating monochrometer is also available to allow the spectral response characteristics of an FPA to be determined.

AEDC has characterized over 100 arrays of various sizes and types for the Army, Air Force, Ballistic Missile Defense Organization (BMDO), and various other customers. Arrays from both technology development and system programs have been tested for application in seeker and surveillance systems. Past experience has shown that the test time spent at the focal plane level is invaluable as these focal planes are integrated into sensor systems and receive further T&E.

Focal Plane Characterization Chamber (FPCC)

The FPCC, completed in 1986, was designed and built to provide precision radiometric characterization of multiple infrared focal plane arrays in a vacuum cryogenic environment. A schematic that shows the major hardware components in the FPCC is provided. Inside the gaseous helium-cooled, optically tight liner is the source package used for flood source testing, during which the array is uniformly irradiated with IR radiation, and spot source testing, in which the target energy is focused onto a single pixel. The IR source package consists of a heated cavity emitter, an aperture wheel, a spectral filter wheel, a diffuser wheel, a linear translation stage, a chopper assembly, and a background source. The cavity can be operated at temperatures ranging from 200 to 800 K. A second IR source, designated as the background source, is mounted on the front of the source package to allow background radiation that is independent of the target radiation to be imposed on the array. A shutter assembly permits the background source to be blocked when minimum background conditions are required. The entire source package is mounted on a three-axis positioning system. The FPCC configuration provides a number of inherent



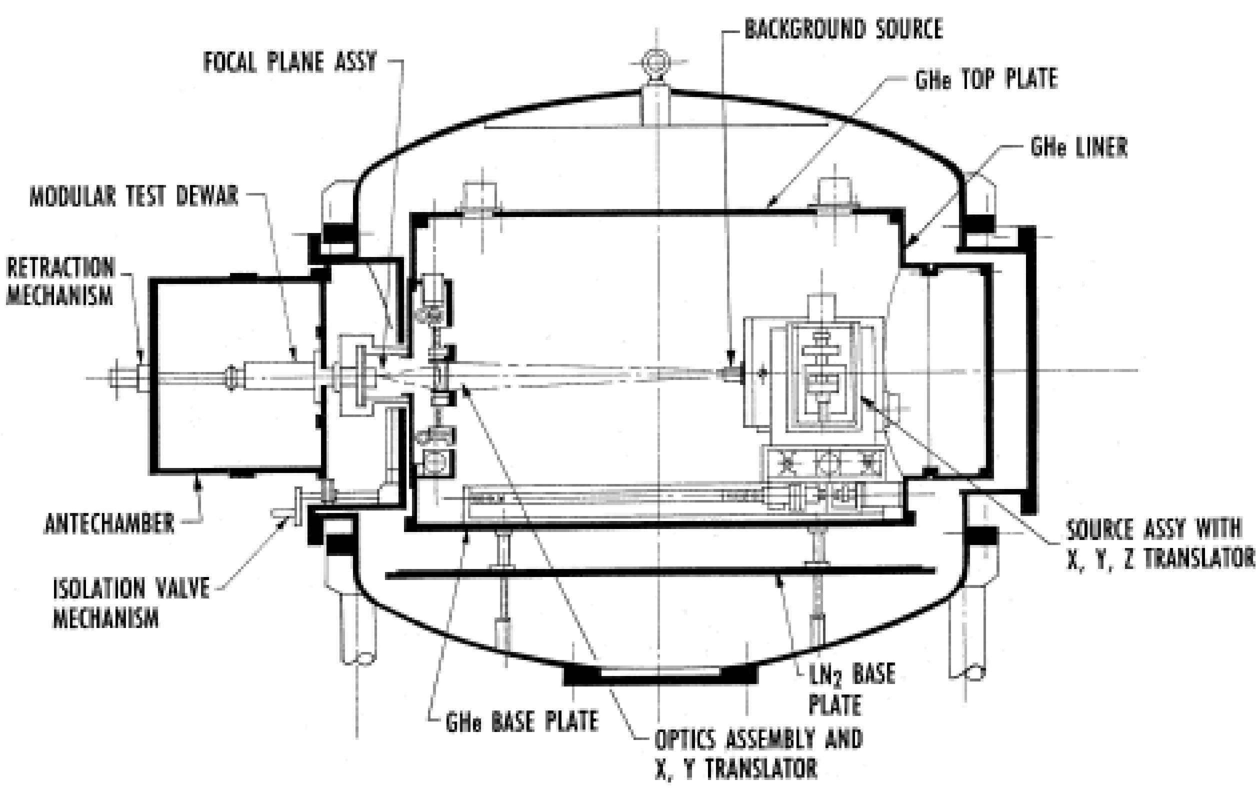
Typical Flow of Hybrid Focal Plane Array Testing at AEDC

design and operational advantages. Several types of testing can be performed during the same test installation. In the flood source configuration, no optical elements are located between the output aperture of the target source and the FPA, thereby reducing the radiometric uncertainty in the measurement. Because of the source-to-FPA geometry, the radiation illuminating the array is highly uniform, even for very large arrays. The FPCC data acquisition and control system can provide data processing and storage for 20 output channels simultaneously.

A demagnified image of the target source aperture can be projected onto the FPA under test using the FPCC optical system. The optical package is mounted on a two-axis drive system that moves the optics from the stowed flood source position into position for spot source testing. The lens assembly is a germanium doublet that is optimized for operation at 10 μm and demagnifies the source aperture by a factor of five. A 10 μm laser diode is mounted on the optics drive assembly. The laser-diode is used to impose a high-intensity flash on the FPA.

Radiometric Calibration System (RCS)

A radiometric calibration system was developed for use with the DWSG facility. The blackbody source assembly for the RCS contains a reentrant conical cavity radiator with an aperture wheel, filter wheel, and chopper wheel. The blackbody source has an operating temperature range of 100 K to 800 K. The NIST-traceable blackbody sources can be used to characterize the test article against broadband and mission band flux. The aperture wheel contains eight apertures (with a maximum diameter of 0.250 in.) and a blank position. A filter wheel that allows the desired spectral bandpass to be selected is provided. It contains eight filter positions with mounting provisions for 1-in.-diam filters. Some of the positions contain blanks that can be used to evaluate radiometric background within the dewar. Filters can be selected and installed that allow radiometric measurements to be made directly in the spectral bands of interest. Control and operation of the RCS can be provided by either the FPCC or DWSG data acquisition and control systems.



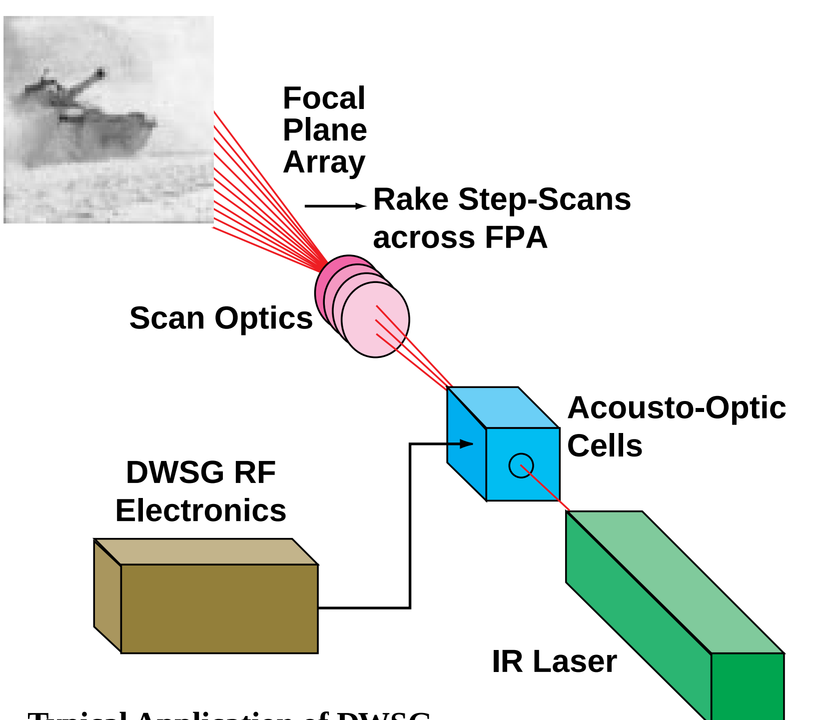
Focal Plane Characterization Chamber

Direct Write Scene Generator (DWSG)

The Direct Write Scene Generator capability was procured through Central Test and Evaluation Investment Program (CTEIP) funding to address tri-service T&E requirements that were not being met by existing national assets. In particular, the system was developed to simulate the real world, complex scenes that today's sensor systems must be able to process rapidly in order to provide accurate information to battle management command and control decision makers. These scenes contain diverse combinations of backgrounds, targets, and mission profiles as defined by the system's particular mission.

As a result of the investment made in the DWSG, the nation has a capability that is key to reducing program risk and downstream costs by providing:

- Design trade-offs during the early development process
- Validation of modeling and simulation tools using hardware in the loop
- Parametric studies on FPA/algorithm performance given changes to the mission scenario and background phenomonology assumptions
- Early operational assessments and interface to other architecture assets
- Evaluation of Sensor Calibration Algorithms
- Simulation of the effects of degraded sensor components (optics, focal plane, and stray light control baffles)



Typical Application of DWSG.

The Direct Write Scene Generator capability is used to test visible and IR sensor sub-systems.

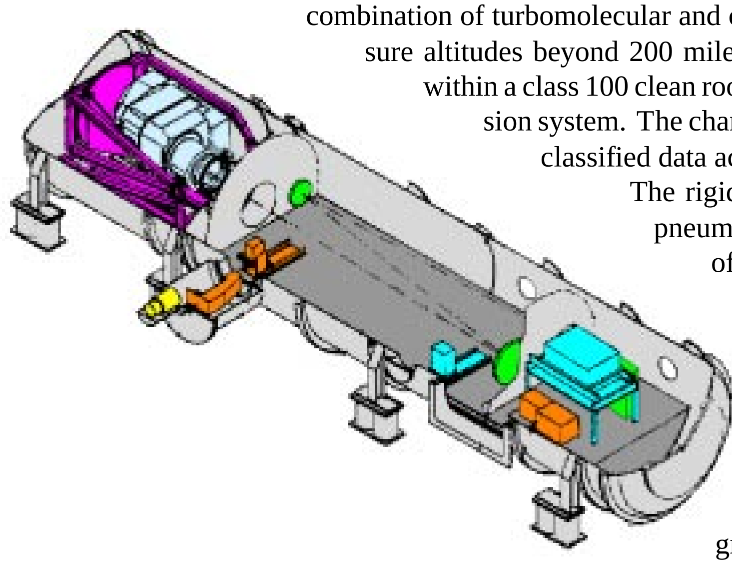
The sensor's mission is simulated by projecting complex scenes directly onto the FPA in real ime. These complex scenes are used to test a sensor's capability to detect, track, and discriminate targets against realistic backgrounds. The key to the DWSG technique is the use of acousto-optic devices to position and control the intensity of a laser beam that paints a scene onto a focal plane. This technique is analogous to an electron gun painting pictures directly onto a television screen. The test approach illustrates how a mission scenario is broken down into a sequence of individual target and background scene frames and overlaid with the telescope optical transfer function and the calibration factors. The frames of information are fed into a complex electronic system that controls the acousto-optic devices to project them onto the FPA in real time.

The DWSG is synchronized to the FPA integration time to ensure proper registration of each frame or image. The image processing system is capable of controlling this synchronization, as well as creating, editing, and displaying the contents of the scene. The DWSG was designed with the versatility to accept scene data from a variety of sources, such as the Synthetic Scene Generation Model (SSGM) and the validated BMDO signature and background data which resides at AEDC's Advanced Missile Signature Center (AMSC).

The advantage of an electronically-controlled, computer-programmable system is the ease of storage and playback of scenes which facilitates comparison testing between various FPAs or doing extensive parametric studies on target and background conditions. The strengths of the DWSG system are (1) relatively unlimited scene content (blooming targets, complex backgrounds, plumes, gamma events), (2) compatibility with staring or scanning FPAs, (3) absence of moving parts in the cryovacuum environment, and (4) lower operating costs than traditional sensor test facilities.

7V Sensor Test Chamber

The 7V chamber has been the primary sensor calibration facility at the Center since the early 1970s. Since it inception, 7V has supported the functional checkout and calibration of approximately 40 sensors. Significant performance upgrades were completed in March 1994, resulting in an advanced capability for the next generation of seeker and surveillance sensors. The 7V chamber is 7-ft in diameter and 21-ft long and contains a light-tight cryogenically cooled liner (20 K) for low radiometric background, to simulate deep-space conditions. A combination of turbomolecular and cryopumps can be used to attain simulated pressure altitudes beyond 200 miles (less than 10^{-7} torr). The chamber is housed within a class 100 clean room and is vibrati s on isolated via an airbag suspension system. The chamber control room is TEMPEST-rated to support classified data acquisition requirements.



Aerospace Chamber 7V

The rigid design of the optical bench, coupled with the pneumatic suspension system provides an optical line-of-sight vibrational stability of 3 μrad. The sensor under test can be mounted on a 3-degree-of-freedom positioner and housed in an ante-chamber that is 7-ft in diameter and 6-ft long. The sensor is interfaced to the cold test volume through an interleaved cold baffle; this allows the sensor to make pitch, roll, or yaw movements without compromising the low background. The sensor can also be mounted directly to the chamber or to the Sensor Isolation Valve that allows isolation of the sensor from the test volume. Collimated radiation from the target and calibration sources is provided by a diffraction-limited, two-element mirror system with a 50-cm exit pupil aperture and a 1.4-deg field of view (FOV). A high -speed scan mirror or a two-axis scan table can position the target statically or dynamically over the entire collimator FOV.

Chamber 7V began supporting the T&E needs of the Ground Based Interceptor (GBI) program shortly after its operational capability was established.

Chamber 7V with Flight Sensor Installed

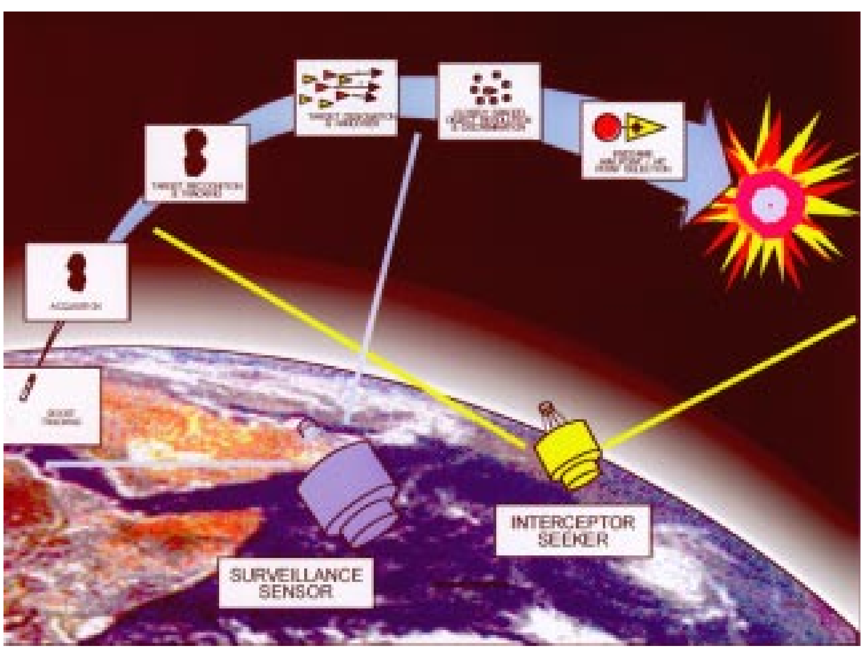
7V Target and Mission Simulation

The 7V chamber incorporates an extensive capability for mission simulation, providing target and background sources for both above- and below-the-horizon tracking, discrimination, and intercept testing. The wide variety of high-fidelity radiometric sources provides background and targets which are all radiometrically traceable to the National Institute of Standards and Technology (NIST). The sources are first used to calibrate the IR sensors, then to obtain mission performance data on the sensor/telescope combination. Calibration includes both broadband and spectral radiometric data and goniometric data for target tracking calibration. Performance data include such issues as target acquisition against complex backgrounds, resolution of closely spaced objects, discrimination of real targets from decoys, target centroiding, track files for targeting accuracy, and end-game dynamics for aim point/hit point determination. Targets range from plumes/cold body simulation (to be added later) to reentry vehicles and decoys. Each target can have a preprogrammed intensity and/or temperature change profile which can be varied independently over a wide range of parameters. The targets can be superimposed on backgrounds ranging from hard earth scenes (to be provided later) and earth limb gradients to uniform, variable-intensity space background.

Closely spaced objects are simulated using dual blackbody targets with independent control of target intensity, position, and color temperature. Each source has temporal intensity variation to simulate a coning target, along with a wide selection of pinhole patterns and sizes, and spectral band pass filters can be added to meet test customer needs. One of the CSO sources also has a visible output using a quartz halide filament bulb with bandpass filters and variable intensity. Simulation of complex target scenarios is provided in an advanced scene generator called the Cryogenic Resistor Array Infrared Scene Projector (CRISP). The CRISP generates dynamic patterns of 1 to 400 fully independent targets using an array of 512 by 512 heated resistor pixels. Each 30-μrad point target is generated by a subarray of 6 by 6 pixels, which allows target motion to be controlled in 5-μrad steps. Each pixel is individually addressable over a temperature range of 20 to 400 K, controlled within 1 K, with response of 10 Hz over the full range. The array fill factor is 90 percent with surface emittance of about 70 percent with spectral characteristics of a graybody.

The chamber offers state-of-the-art radiometric calibration for both broadband and spectral output with point and extended sources. An extensive calibration measurement history has established an excellent statistical database to document the accuracy of the sources to better than 3 percent with precision of less than 2 percent traceable to NIST through the AEDC secondary standard blackbody (AEDC blackbody was NIST calibrated). This standard source is located in the chamber for *in-situ* calibration checks at any time. Spectral calibration is provided using a circular variable filter (CVF) over the 2- to 14.5-μm wavelength band or with a 2-grating monochrometer over a wider range with finer resolution. A flood source and a uniform temperature heated plate are also available.

Calibration of target position is accomplished by the Alignment Monitor System (AMS). The AMS is an infrared sensor equipped with a 256 by 256 Indium Antimonide (InSb) focal plane covering a 0.75-deg square portion of the collimator field of view. The AMS and its image analysis electronics and subpixel centroid algorithm provide absolute target position to an angular accuracy of 5 μrad.



Target and Mission Simulation

Thermal/Vacuum

AEDC has conducted many thermal/vacuum tests in support of aerospace programs. The thermal/vacuum facilities can be grouped into a discussion of the small research chambers, the 10V chamber, the 12V chamber, and the Mark I chamber. These chambers can provide thermal cycling/balance tests using any combination of IR lamp arrays, heated wire arrays, and heated gaseous nitrogen panels. Contamination is measured with quartz crystla microbalances (QCM) and optical witness plates. The chambers are equipped with several data acquisition and data reduction channels that are sampled several times per second. Data display and plotting can be tailored to meet customer needs. Video camera coverage can be provided, along with specialized data acquisition such as high-speed photography.

Research Chambers

AEDC's Space Research Laboratory houses cryovacuum test chambers for verifying the operational readiness of test article components and/or subsystems prior to full-scale assembly and test. These chambers range in size from 1-ft diam x 1-ft long up to 4-ft diam x 10-ft long. The Research Laboratory supports (1) liquid helium production for all chambers or test hardware, (2) subsystem R&D for larger space chambers, and (3) R&D testing for government and commercial products.

The 4 x 10 chamber is the largest general-purpose test cell in the research laboratory. The 4-ft-diam by 10-ft-long horizontal chamber and is equipped with a 77 K or 20 K cryogenically cooled liner. The chamber can accommodate a large variety of test requirements. The 7A chamber is a general- purpose chamber 3-ft dia. by 5-ft long with a 77 K or 20 K cryogenically cooled liner. The chamber is used for component functional checkout and development. The Ultra High Vacuum (UHV) chamber provides a low radiometric background (<10^{10} photons/sec) for use in infrared source calibration and characterization. The low background provides a test bed for infrared detectors and cold electronics evaluation. The research laboratory maintains two cryopump chambers that have been assembled from off-the-shelf Leybold-Hereaus RPK10000 cryopumps. The cryopump chambers with added turbopumps provide approximately 1 x 10^{-8} torr vacuum and the capability of cooling to temperatures to as low as 10 K for an extended period. These chambers have been used extensively for drive motor checkout and testing of Midcourse Space Experiment (MSX) satellite QCMs (flight hardware). The 7 x 8, 7-ft-diam by 8-ft-long chamber has provided a broad range of tests including NASA/AXAF flight hardware cables which required the NASA SPEC 1238 Contamination Certification of 1Hz/hr/24 hrs on a TQCM, and more recently, the Space Station Kevlar™ 29 Debris Shield bake-out.

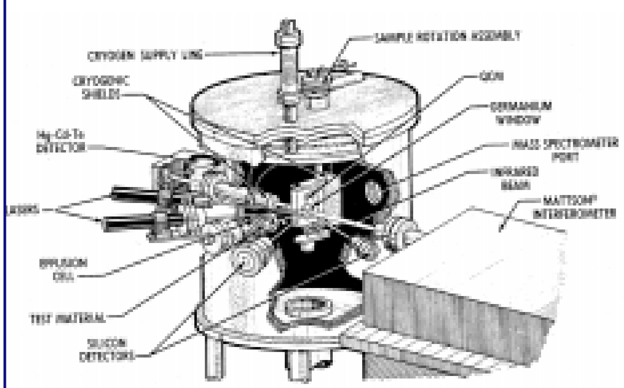
AEDC Technicians Install NASA/AXAF Cables for Testing in the 4 x 10 Research Chamber

Spacecraft Contamination Capabilities

Spacecraft contamination capabilities at AEDC include measurement of contaminant effects on optical properties, solar cell efficiency degradation due to contaminants, outgassing properties of satellite and ground test chamber materials, and contamination monitoring device performance, such as QCM and surface acoustic wave (SAW) mass detectors. AEDC has also supported long-term performance evaluations, including preflight qualification, of QCMs at temperatures as low as 10 K, and reflective property changes in samples returned from NASA's Long Duration Exposure Facility (LDEF) after retrieval from space. From this experience, AEDC has developed a suite of dedicated research chambers, established an optical properties database for satellite materials, and developed analytical math models to determine optical properties of contaminants and predict their surface effects. The following spacecraft contamination chambers are available for use:

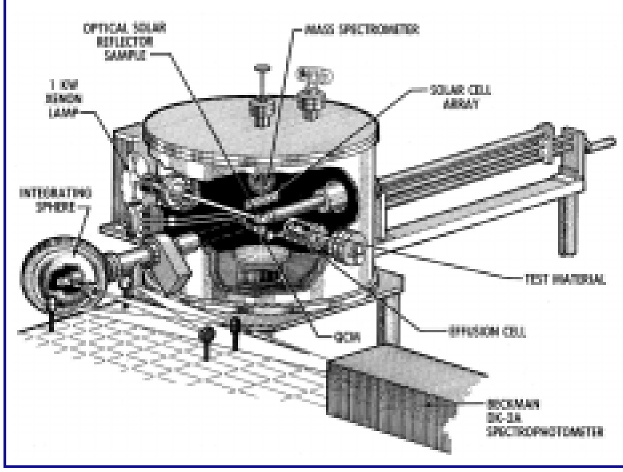
Cryogenic Optical Properties (COP) Chamber: The COP Chamber is used to determine the effects of thin-film contaminants condensed on cryogenically cooled optical components and the optical properties (refractive and absorptive indices) for the cryogenic films. The COP Chamber is also used for investigating the optical effects of pure gases condensed on cryogenically cooled optical surfaces. Data are obtained over a wavelength range from approximately 2.5 to 20.0 µm and for substrates cooled to both 77 K and 20 K.

Cryogenic Optical Properties (COP) Chamber



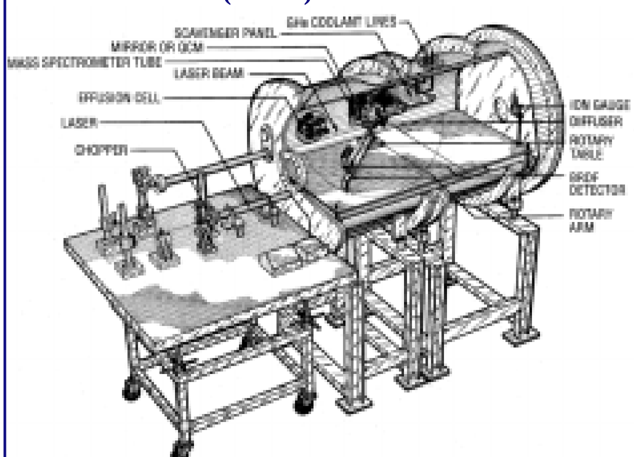
Solar Absorptance Measurements (SAM) Chamber: The SAM Chamber performs reflectance studies of contaminated thermal control surfaces and measures contamination effects on solar cell efficiencies. The surfaces in this chamber are maintained at room temperature. Reflectance measurements are made over the 0.25- to 2.5-mm wavelength range, which covers the range where most solar energy is concentrated.

Solar Absorptance Measurements (SAM) Chamber



Bidirectional Reflectance Distribution Function (BRDF) Chamber: The BRDF Chamber measures the scattering effects of condensed contaminants on cryogenically cooled highly polished mirrors using a He-Ne (0.6328 µm) or CO_2 (10.6 µm) laser beam. An effusive source provides a means of depositing contaminants from a satellite material by condensing them on the cold test surface. The mirror test surfaces can be cooled to 77 K or 20 K.

Bidirectional Reflectance Distribution Function (BRDF) Chamber



Vacuum Ultraviolet (VUV) Chamber: A dedicated research chamber has been constructed for measurement of the effects of VUV radiation or contaminant deposition on optical surfaces and solar absorptance changes in optics due to deposition of material outgassing products.

As a result of the QCM evaluations for the BMDO-sponsored MSX satellite, AEDC was chosen to participate in the analysis of the QCM flight data after launch (April 1996). The QCMs have been invaluable in the characterization of the contamination surrounding the spacecraft and also within the cryogenically cooled Spirit 3 telescope. The cryogenic-rated QCM (CQCM) has provided valuable data for determining the contaminant thickness on the 20 K primary mirror of the telescope. Through the use of thermogravimetric analyses (TGA) performed at carefully chosen flight times, the amount and species of the previously condensed contaminants have been determined. The film thickness determined from the CQCM output data was used to correlate this thickness with mirror optical effects such as BRDF and mirror reflectance.

10V Chamber

The AEDC 10V chamber became operational after extensive upgrade and is capable of supporting a broad range of thermal vacuum requirements. The 10V Chamber shares vehicle handling and target systems as well as support infrastructure with the 7V chamber. The 10V chamber is a horizontal cylinder, 10 ft in diameter and 30 ft long. The chamber contains cryogenically cooled optical benches supported from below by a large seismic mass. The 300,000-lb seismic mass acts as a common optical table tying all optical elements together. Each optical bench is mounted to the seismic mass via columns that penetrate the vacuum shell though vibration isolation diaphragms. The measured line-of sight vibration stability is less than 1 μrad. The chamber is fitted with a light-tight 20 K GHe liner to simulate the background radiation of space. A combination of turbomolecular and cryopumps can be used to attain simulated pressure altitudes beyond 200 miles (less than 10^{-7} torr). The chamber is housed within a Class 1000 clean room and is vibration isolated via an airbag suspension system. A class 100 clean tent is available to support test articles with high cleanliness requirements.

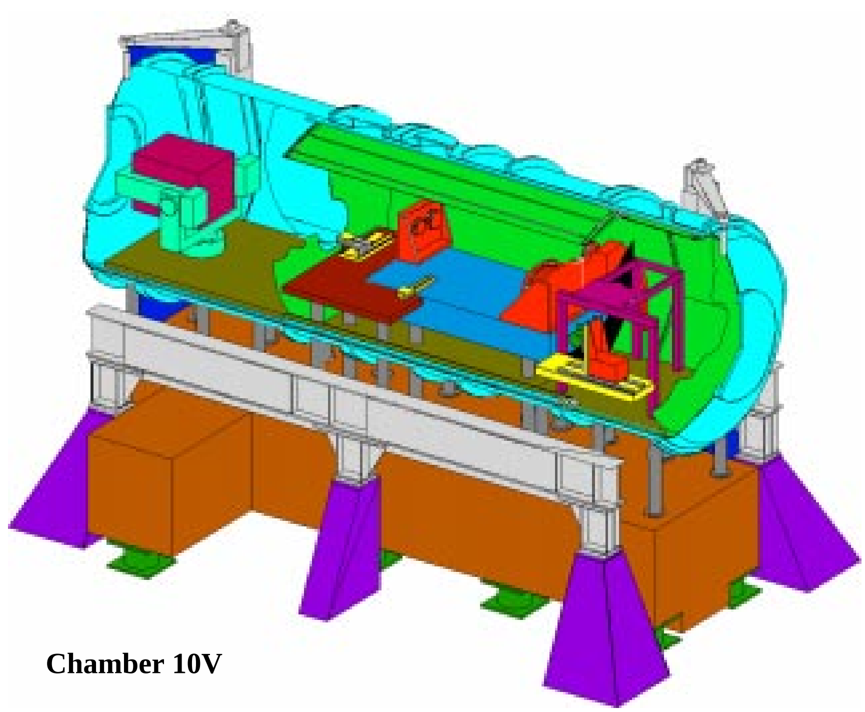
The capabilities of the 10V are uniquely suited for "deep space" testing of optical elements at any required temperature for space telescopes, sensors, test chambers, etc. AEDC has a significant investment in the latest and most sophisticated optical design and analysis codes; measuring equipment such as interferometers and laser goniometers; and scientists and engineers who are world class in the use of these tools. For example, interferometric data taken from a cryogenic optical system are readily converted to optical path differences (OPD) using a polynomial regression. The response of the system (called the Point Spread Function or PSF) can be calculated from the set of OPD. Finally, a Fourier Transform of the PSF yields the Optical Transfer Function (OTF). With the OTF, the user has the pertinent information about the optical system required to render judgments on optical quality or to use the optical system in performance calculations.

An example of versatility includes the NASA/MSFC's Advanced X-Ray Astrophysics Facility Proto-Flight Solar Array Panel which required thermal cycling from 72°C to –201°C. The AXAF satellite's highly elliptical orbit was simulated in the 10V chamber, resulting in deep space flight hardware qualification of 34 different materials at temperatures beyond normal space flight conditions.

12V Chamber

The 12V chamber is 12-ft in diameter by 35 ft high, and is lined with 77 K LN_2 cryopanel surfaces, which are used to simulate the thermal environment of space. The 12V chamber has a GHe-cooled inner liner, or shroud, which can be cooled and maintained at 10 K and evacuated to the 10^{-8}-torr level.

The 12V chamber is equipped with an off-axis solar simulator system consisting of an array of seven



Chamber 10V

xenon arc lamps, an integrator lens system, and mirror to produce a well-collimated, uniform beam over an 8-ft-diam by 8-ft-high test volume. The xenon arc lamps produce an energy spectrum very similar to that of the sun. A multi-element integrating lens is used to attain a beam uniformity factor of greater than 95 percent. The collimating mirror, located at the top of the chamber produces an 8-ft-diam solar beam at the test article location; the beam collimation factor is better than 98 percent. The beam irradiance can be adjusted from 0 to 1.5 solar constants by varying the number of lamps and the lamp voltage.

Solar Beam in 12V Chamber

AEDC's 12V chamber has been involved with several Space Station thermal vacuum tests. The first test was the "hatch" that covers a passageway between Space Station elements and provides a means by which any element can be sealed off from the rest of the Space Station. The test involved several thermal cycles on the hatch to determine the survivability of a latching mechanism. A second 12V entry tested the Space Station cupola, which serves as an observation area for the astronauts. The test involved several thermal cycles using internal heaters to control internal temperatures. AEDC was able to begin testing after only four days from initial contact with NASA/Boeing. The most recent Space Station test in the 12V chamber was the Active and Passive Common Berthing Mechanism. Long-term thermal balancing involved using solar-on, solar-off with LN_2 background and rotating the test article to characterize the thermal load requirements while simulating orbital conditions. Other tests include characterizing a hybrid solar array concentrator for NASA's Lewis and Clark technology demonstrator satellite program.

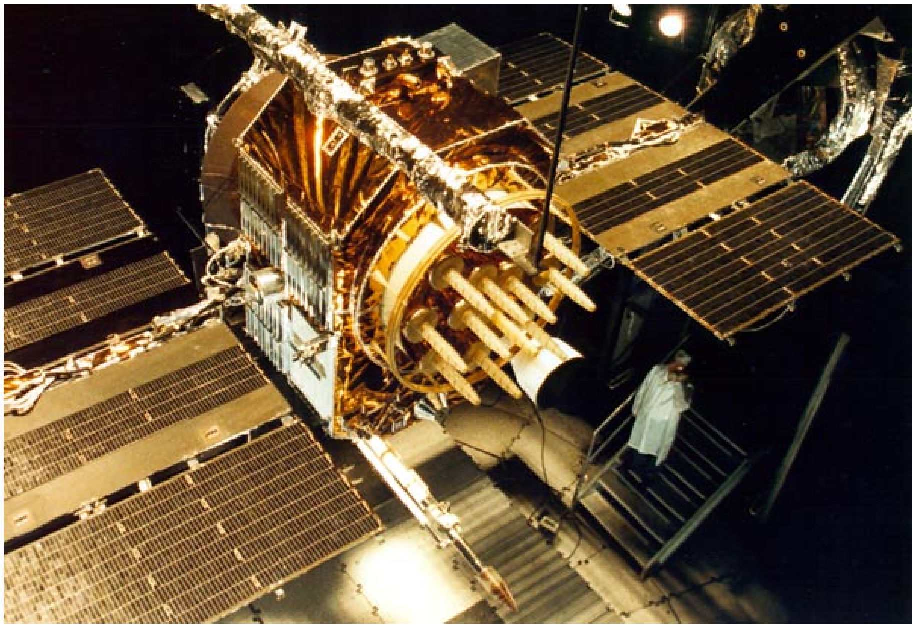
NASA Hatch Latch Test in 12V

The infrared (IR) signature of a variety of space vehicles or vehicle components can be measured in the 12V chamber. The chamber walls and floor are LN_2 cooled to maintain a simulated background radiation level of 77 K. A two-deg-of-freedom vehicle handling system (pitch and spin) is used to simulate orbital vehicle dynamic motion with respect to the sun to attain proper solar radiant heat-transfer profiles. A circular variable filter spectrometer (CVFS) is used to measure the infrared signature of the test article. The CVFS measures IR radiation from 5 to 22 µm.

Mark I Chamber

AEDC has conducted space environmental (thermal vacuum) tests for several major aerospace programs in the Mark I. At 82 ft high and 42 ft in diameter, Mark I is ideally suited for testing system level and flight hardware. The Mark I chamber is internally lined with 77 K LN_2 walls and can be evacuated to 1.4 x

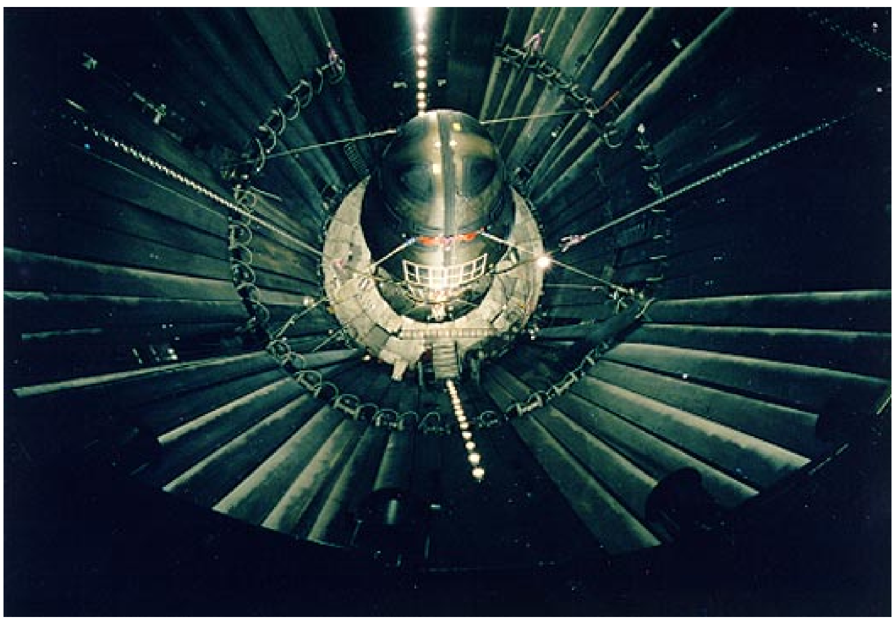
10^{-7} torr. A picture of the Block II GPS satellite installed in the Mark I chamber is shown at right.



Mark I GPS Test

By taking advantage of the height of Mark I, 2 sec of zero-gravity simulation can be provided. Catch mechanisms stop the article's fall at the bottom of the chamber. AEDC has conducted space dynamics type tests for several major aerospace programs in the Mark I chamber. Typical space dynamics-testing is performed within a few tenths of a second and requires 1 x 10^{-4} torr vacuum levels (150,000 to 350,000 ft altitude) with an ambient thermal environment. Space dynamics tests in the Mark I have included full-scale separations of the Titan 34D, Titan IV, and Delta III payload fairings. A photograph of the Delta III fairing test, conducted in FY1998, is shown below.

Also initiated in the Mark I test chamber was a series of tests in support of a cold neutron source R&D effort for DoE/Oak Ridge National Laboratory. Testing provided proof of concept and hardware operations, math model validation, operational experience, software and hardware capabilities, and limits. The tests involved prototyping a closed-loop GHe circulation system. The cold neutron source is a medical research tool which uses a 20 K hydrogen loop injected into a nuclear reactor. The hydrogen absorbs enough energy of the nuclear reactors neutrons to enable a "focusing of neutrons" to treat inoperable brain tumor patients. Hydrogen was circulated and cooled down to the supercritical region at 20 K at 14 bar using AEDC's 3 kW GHe refrigerator. Upon reaching the desired operating temperatures, 3-kW of heat was applied to the loop to simulate an insertion into a nuclear reactor.



Delta III Fairing Test in Mark I Chamber

DECADE DoD Center for Radiation Effects Testing

The DECADE Radiation Test Facility (DRTF) is being built at AEDC with the Defense Threat Reduction Agency (DTRA) as the lead organization. DECADE is a new, advanced generation nuclear test facility designed to test twenty-first century space and missile systems and their components against nuclear weapons effects. The first DECADE is configured in the hot X-ray mode with a scheduled Initial Operating Capability (IOC) of May 1999. Planned additions will provide both medium and cold X-rays by the year 2000.

DECADE will employ the newly developed inductive energy storage technology to provide the high power levels (10 TWper quad) required to produce threat level outputs of up to 16 krad of radiation over 2250 cm^2. Ongoing DTRA research and development programs will result in planned product performance improvements to include increased quad output, decreased endpoint voltage, high dose, and high dose rate options. Significant improvements in Plasma Radiation Source (PRS) output are also projected, along with associated debris mitigation capability.

A Central Test and Evaluation Investment Program (CTEIP) proposal has been submitted to complete this facility with advanced system test capabilities that currently do not exist. At Full Operating Capability (FOC), the DECADE Radiation Test Facility-Enhanced (DRTF-E) will provide: (1) large area hot and cold X-rays utilizing two DECADE quads; (2) prompt gamma radiation; (3) debris gamma and beta radiation capability; and (4) an advanced test bed consisting of a cryogenic vacuum chamber with infrared scene generation and nuclear clutter simulation. At present, prompt radiation testing is confined to single radiation source testing (X-rays, gamma, etc.). Unlike single environment facilities, DRTF-E will focus on subsystem/system level testing with multiple environment capabilities that more accurately simulate the complex radiation time history of an exo-atmospheric event. This modern test facility is the only DoD facility with capability to demonstrate that systems can meet their high confidence requirements and survive and function in prompt radiation environments that might be experienced by the system during its combat mission.

The facility is designed with a number of user-oriented features: 1,000 ft^2 of floor space for user data acquisition needs, dedicated test setup area, user shop, and classified testing capability, along with data analysis and storage capabilities.

DECADE X-ray Simulator Characteristics

Radiation Source Specifications:

Source:	Bremsstrahlung
Average Yield*/Dose:	15-20 krad (Si)
Uniformity**:	2.0
Area:	,250 cm^2
Pulse Width FWHM:	≤ 45 nsec
Average Peak:	Diode Voltage not to exceed 18 MV

* Area-weighted average
** Uniformity (U) is defined as the ratio of Maximum Radiation to Minimum Radiation over the total area measured in a rectangle with an aspect ratio less than or equal to 1.2:1.0.

Fully Rated Operations:

The facility has the capability to support three shots a day. It can be configured to accommodate various security levels including Sensitive Compartmented Information (SCI).

User Data Acquisition System (UDAS):

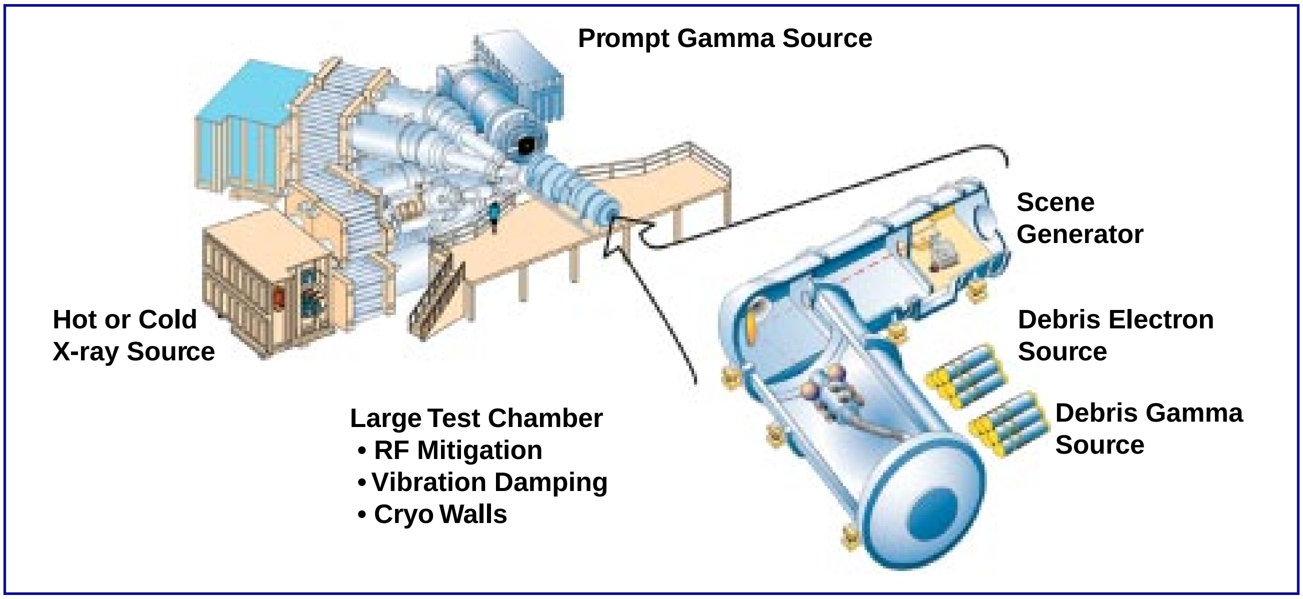
The data storage and management system capability is sufficient to record, analyze, and archive collected data. For personal computer hookup, the UDAS network design supports both IBM and Macintosh computers with an Ethernet connection. The UDAS will use DEC Pathworks networking software, which supports Windows™ 95, Windows-NT, DECnet, TCP/IP, and Appletalk.

UDAS User Computer Hardware:

Two DEC AlphaServer 2100 4/275 dual processors
128 Mbytes memory
10 Gbytes disk storage
20 Gbyte linear tape, CD-ROM
4-mm DAT tape, 9-track tape
Four weeks on-line archival of test data

UDAS Software:

VMS, Windows-NT, OSF/1 operating systems
FORTRAN, C and C++ compilers
DECnet, TCP/IP,NFS Network Software
IDL Data Processing and Analysis



Modular Bremsstrahlung Source (MBS)

The AEDC Modular Bremsstrahlung Source (MBS) operates in a lower energy range than DECADE. The facility is used for SGEMP, IEMP, and dose enhancement effects testing. This simulator is capable of twelve shots per hour, and a vacuum test chamber is available. Both the radiation pulse width and rise time are adjustable over limited ranges. The simulator facility has all the required manpower and materials necessary to run the generator and accurately diagnose the radiation environment.

Bremsstrahlung Radiation Environment:

Adjustable 100-300 keV endpoint voltage

165-keV mean energy

3000-cm^2 target area

Up to 410 rads mean dose and up to 1 x 10^{10} rads/sec mean dose rate

X-ray pulse width 30-nsec FWHM with 15-nsec risetime

Vacuum test chamber: 2 ft diam x 3 ft in length

Source C_L is ~3.5 ft above the test cell floor

Dosimetry/Diagnostics:

PIN diodes, Gorbics spheres, calorimeters (Ta), pin-hole camera, TLDs (CaF_2),

Three-pin spectrometer

Operational Information:

Test operation includes generator operation, radiation diagnostics, data acquisition, data reduction, and specialized assistance to the user.

Experienced technical assistance is available to meet special needs.

Normal operation: 30 to 75 shots per day

State-of-the-art, user-friendly facilities available: office space, computers, preparation rooms, TLD readers, etc.

Control room will accommodate user equipment.

DECADE MBS Test Unit

Facility Instrumentation:

Initial instrument setup in less than 4 hours
Processed data available in 20 min after shot
Quick look within 5 min to permit planning for next shot parameters
Noise floor ~10 mV peak during pulse, 10 mV after 100 msec
148 channels available (expansion to 350 is planned)

Common Equipment Parameters:

Analog Bandwidth	Sampling Rate (samples/sec)	Number of Channels
DC – 1 GHz	4G	5
DC - 400 MHz	2G	47
DC - 100 MHz	500 M	32
DC - 10 MHz	50 M	32
DC - 100 KHz	500 K	32

Fiber-optic links are connected to AEDC Exemplar and Cray mainframes and to the DEC Alpha workstation (located inside the SCIF area) for additional computational resources. Various codes are available to perform analysis of circuits, pulse power, radiation sources, and effects on electronics.

Related Facilities

AEDC is the nation's largest ground test center for flight simulation test, operating more than 50 separate facilities with altitude capabilities from sealevel to deep-space conditions. In addition to space chambers and nuclear effects facilities; wind tunnels, arc heaters, ballistic ranges, rocket test cells, and turbine test cells are also available to meet customer testing requirements. Specific information on these facilities may be obtained from AEDC/Directorate of Operations or AEDC/Public Affairs. Of particular interest to launch vehicle developers are:

Rocket Test Facilities

The Center's Engine Test Facility (ETF) test cells are used for development and evaluation testing of propulsion systems for advanced aircraft, missiles, satellites, and space vehicles. Rocket propulsion sytems that can be tested in ETF range from small units of a few pounds thrust to much larger rocket motors and engines in the hundreds of thousands of pounds thrust. Tests check the rocket's ignition, measure its thrust, propellant and burning, nozzle control, and shutdown characteristics - important factors in ensuring accuracy and range. To simulate the extreme altitudes at which rockets operate, the pumping effect from the rocket exhaust and steam ejectors is used to supplement facility mechanical pumping to maintain low pressures in the test cells.

Propulsion Wind Tunnels

AEDC operates 16-ft supersonic and transonic wind tunnels and a 4-ft transonic wind tunnel. The 16-ft tunnels are equipped with a scavenging system to remove exhaust products when testing propulsion systems. The tunnels have been used to test launch vehicle aerodynamics, plume interactions with the airstream, and tactical missiles.

Hypersonic Test Facilities

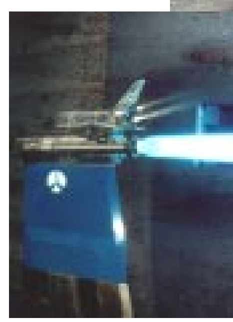
AEDC uses a variety of hypersonic test facilities to assess vehicle performance. AEDC's aerothermal facilities are the highest pressure arc-heated facilities in the U. S., providing unique, high-enthalpy environments for testing materials. Aerodynamic testing in the hypersonic regime is accomplished in Tunnels A, B, and C and in the Aeropropulsion Test Unit. The Hypervelocity Range G Facility can provide simulation of high stagnation enthalpy and pressures for ablation/erosion and aerodynamic testing of launch vehicle systems.

Advanced Missile Signature Center (AMSC)

The AMSC is a national archive of plume signature data for a variety of ballistic and tactical missiles. The AMSC employs a wide array of data analysis tools and JANNAF models to assess data quality and phenomena. Other resources include a complete video post-production facility and real-time video digitizing system, and a distributed computer system serving BMDO and SIPRNET classified networks.

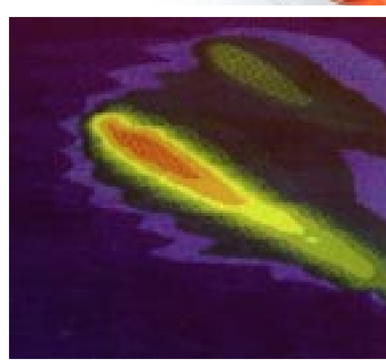
Titan IV LR91 Engine

Titan IV Aerodynamic Test in PWT 16T.



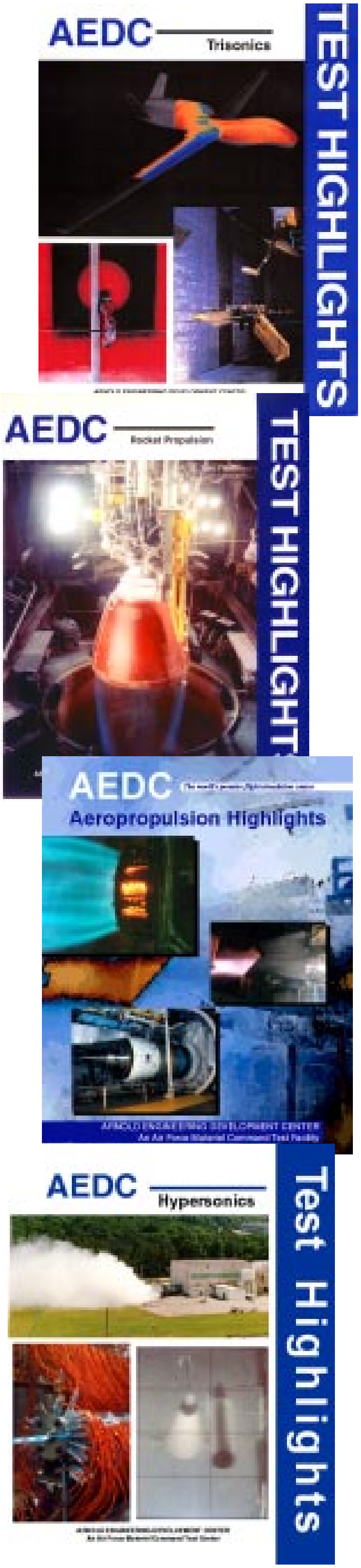
Space Shuttle in PWT 16T

Arc Heater



Computer-Generated Plume

AEDC Highlights



http:/www.arnold.af.mil/highlights

- **Trisonics**
  This publication focuses on aerodynamic testing and associated analysis and evaluation in AEDC's transonic, supersonic, and hypersonic wind tunnel facilities.

- **Rocket Propulsion**
  This publication focuses on the simulated altitude rocket test and evaluation capabilities at AEDC and related success stories.

- **Aeropropulsion**
  This publication focuses on aeropropulsion testing and evaluation at AEDC.

- **Hypersonics**
  This Spring 1999 publication focuses on hypersonic testing and evaluation including AEDC's ballistic ranges, arcs, and hypersonic tunnel 9.

- **Special Editions**
  Coming in Spring 1999
  - Commercial Utilization of AEDC – A Success Story
  - AEDC – Contributions to National Defense

AEDC Test Facilities
(Nominal Values)

ENGINE TEST FACILITY	Test Section Size: Cross Section, ft	Test Section Size: Length, ft	Total Temperature, °R	Speed Range	Pressure Altitude (Nominal), ft	Capacity of Installed Thrust Stand, lb	Primary Use*
Propulsion Development Test Cell T-1	12.3 diam	39 to 57	380 to 1,110	Mach 0 to 3.0	Sea Level to 80,000	30,000	(2) (6) (9)
Propulsion Development Test Cell T-2	12.3 diam	42 to 50.5	380 to 1,110	Mach 0 to 3.0	Sea Level to 80,000	30,000	(2) (6) (9)
Propulsion Development Test Cell T-3	12 diam	15	450 to 1,660	Mach 0 to 4.0	Sea Level to 100,000	20,000	(2) (3) (6) (9) (11)
Propulsion Development Test Cell T-4	12.3 diam	39 to 47.8	380 to 1,110	Mach 0 to 3.0	Sea Level to 80,000	50,000	(2) (6) (9)
Propulsion Development Test Cell T-5 ***	7 diam	17	395 to 660	Mach 0 to 2.0	Sea Level to 80,000	2,000	(2) (6) (9)
Propulsion Development Test Cell T-6 ****	3 diam	18	430 to 760	Mach 0 to 3.0	Sea Level to 90,000	None	(1) (3) (4) (6) (7) (11)
Propulsion Development Test Cell T-7 ***	7 diam	9	395 to 1,110	Mach 0 to 3.0	Sea Level to 80,000	1,000	(2) (6) (9)
Propulsion Development Test Cell J-1	16 diam	65	395 to 1,210	Mach 0 to 3.2	Sea Level to 80,000	50,000	(2) (3) (6) (9)
Propulsion Development Test Cell J-2	20 diam	67.3	395 to 1,110	Mach 0 to 3.0	Sea Level to 80,000	50,000	(2) (3) (6) (9)
Propulsion Development Test Cell J-2A****	18.3 diam	32	(Wall, 144)	Static	450,000	20,000	(1) (5) (11)
Rocket Development Test Cell J-3	12 diam	26 High					
	17 diam	20, 30, 40 High	– – –	Static	125,000	200,000	(1) (5)
Rocket Development Test Cell J-4	48 diam	82 High	– – –	Static	100,000	500,000	(1) (5) (11)
Rocket Development Test Cell J-5 ***	16 diam	50	– – –	Static	100,000	300,000	(1) (5) (11)
Rocket Development Test Cell J-6	26 diam	62	– – –	Static	100,000	500,000	(1) (5) (11)
Sea Level Test Cell SL-1 ***	24 x 24	50	Ambient	Static	Sea Level	52,500	(2)
Propulsion Development Test Cell C-1	28 diam	50 to 85	360 to 1,480	Mach 0 to 3.8	Sea Level to 100,000	100,000	(2) (3) (6) (9)
Propulsion Development Test Cell C-2	28 diam	50 to 85	360 to 1,110	Mach 0 to 3.0	Sea Level to 100,000	100,000	(2) (6) (9)

von KARMAN GAS DYNAMICS FACILITY	Test Section Size, in.	Total Pressure, psia	Total Temperature, °R	Speed Range	Pressure Altitude, ft	Dynamic Pressure, psf	Reynolds No./ft ($x10^6$)	Primary Use*
Supersonic Wind Tunnel A	40 x 40	1.5 to 200	530 to 750	Mach 1.5 to 5.5	16,000 to 151,000	53 to 1,780	0.3 to 9.2	(6) (7) (14)
Hypersonic Wind Tunnel B	50 diam	20 to 900	700 to 1,350	Mach 6 to 8	98,000 to 180,000	43 to 590	0.3 to 4.7	(6) (7) (14)
Hypersonic Wind Tunnel C	50 diam	200 to 1,900	1,650 to 1,950	Mach 10	132,000 to 188,000	43 to 430	0.3 to 2.4	(6) (7) (14)
Aerothermal Wind Tunnel C	25 diam Free Jet	200 to 2,000	1,220 to 1,900	Mach 8	95,000 to 149,000	132 to 1,322	0.7 to 7.8	(6) (7) (13)
	25 diam Free Jet	20 to 180	720 to 1,660	Mach 4	56,000 to 105,000	231 to 1,928	0.2 to 8.1	(6) (7) (13)
Aerodynamic and Propulsion Test Unit (APTU)	32 diam	20 to 160	700 to 1,000	Mach 2.20	Sea Level to 40,000	900 to 7,300	3.15	
		20 to 300	700 to 1,200	Mach 2.72	10,000 to 70,000	600 to 9,300	3.16	
	36 diam	40 to 300	700 to 1,300	Mach 3.50	35,000 to 75,000	650 to 4,800	1.10	(1) (3) (4) (6)
	42 diam Free Jet	20 to 240	700 to 1,150	Mach 2.55	Sea Level to 65,000	700 to 8,500	2.17	(7) (9) (11)
		50 to 300	700 to 1,600	Mach 4.10	55,000 to 80,000	500 to 2,900	1.6	(12) (13)
Hypervelocity Range/Track G	120 diam	– – –	– – –	To 24,000 fps	Sea Level to 244,000	– – –	– – –	(8) (10)
Hypervelocity Impact Range S1	Target Tank 30 diam	– – –	– – –	To 32,000 fps	Sea Level to 10^5 torr	– – –	– – –	(10)
Bird Impact Range S3	240 x 144	– – –	– – –	200 to 1,400 fps	Sea Level	– – –	– – –	(10)

	Contoured Nozzle	Reynolds No./ft ($x10^6$)	Supply Pressure Range, atm	Nominal Supply Temp, °R	Usable Run Time, sec
TUNNEL 9	7	3.7 to 15.8	180 to 815	3,460	1 to 5
	8	8.7 to 55.7	135 to 815	1,660	0.2 to 0.75
	10	0.86 to 21.9	35 to 955	1,810	0.2 to 15
	14	0.072 to 6.2	7 to 1,295	3,160	0.7 to 15
	16.5	2.65 to 3.2	1,295 to 1,430	3,260	3.0 to 3.5

	Nozzle Exit Diameter, in.	Model Enthalpy, Btu/lb	Model Pilot Pressure, atm	Mach Number	Erosion Simulation: Dust Particle Diameter, µm	Erosion Simulation: Dust Velocity, fps	Primary Use*
High Enthalpy Ablation Test Unit (HEAT) H1	1.8 to 3.5	2,000 to 9,000	17 to 95	0.75 to 3.00	70 to 200 Graphite	5,800 to 7,300	(13)
High Enthalpy Ablation Test Unit (HEAT) HR **	1.8 to 3.2	2,000 to 5,200	19 to 77	1.1 - 4.0	– – –	– – –	(13)
High Enthalpy Ablation Test Unit (HEAT) H2	4 - 9.8	0.896 to 2,278	0.14 to 3.4	4.0 to 8.0	– – –	– – –	(7) (13)

	System	Type	Size	Max. Specimen Weight, lb	Max. g	Remarks	Primary Use*
Impact, Vibration, and Acceleration Test Unit ****	Vibration	Electrodynamic Ling A249	30-in. diam	2,800 at 10 g rms	75	30K-lb Max. Sine Force 32K-lb Max. Random Force 5.2 kHz, 1.0 in. Double Amp	(1)
	Shock	Electrodynamic Ling A249	30-in. diam	2,000	– – –	Pulse Shapes: Sawtooth, Half-Sine, etc.	
		Parallel-Pendulum	– – –	1,000	– – –	Travel, 2 ft	
	Acceleration	Centrifuge	17-ft rad	2,000	30	– – –	

AEROSPACE CHAMBERS	Test Section Size: Cross Section, ft	Test Section Size: Length, ft	Wall Temp., K	Chamber Empty Pressure, torr	Pressure Altitude, miles (1962 U.S. Std Atm)	Thermal Radiation Simulation	Primary Use*
Mark I	42	(Vert.) 82	77	10^{-7}	210	Collimated Solar and Programmed Heat Flux	(5)
10V	10	(Vert.) 30	77	10^{-7}	200	Tungsten Lamps	
12V	12	(Vert.) 35	77	10^{-7}	200	8-ft-diam Xenon Solar and Programmed Tungsten Lamps	
7V	7	24	<20	10^{-7}	200	N/A	
FPCC	5	5	<20	10^{-7}	200	N/A	
DWSG	Varies	Varies	<20	N/A	200	N/A	
BRDF	3	5	AMB	10^{-5}	AMB	N/A	
COP	2	3	77	10^{-5}	200	N/A	
SAM	2	15	77	10^{-7}	200	Xenon Lamp	
SMOG	2	1	AMB	10^{-5}	AMB	N/A	
7A	3	5	<20	10^{-7}	200	– – –	
UHV	2	3	<20	10^{-7}	200	N/A	
4 X 10	4	10	<20	10^{-7}	200	– – –	
CROVAC	Varies	1	<20	10^{-7}	200	N/A	

DECADE	10-13k Rad(Si), 10,000 cm^2 target area, 1.5 by 2 m test articles in chamber

PROPULSION WIND TUNNEL FACILITY	Test Section Size: Cross Section, ft	Test Section Size: Length, ft	Total Temperature, °R	Speed Range	Pressure Altitude (Nominal), ft	Dynamic Pressure, psf	Reynolds No./ft ($x10^{-6}$)	Primary Use*
Propulsion Wind Tunnel 16T	16 x 16	40	540 to 600	Mach 0.06 to 1.6	Sea Level to 90,000	2 to 1,100	0.2 to 6.0	(6) (9) (14)
Propulsion Wind Tunnel 16S ***	16 x 16	40	580 to 1,080	Mach 1.5 to 4.75	45,000 to 155,000	25 to 550	0.1 to 2.4	(6) (7) (9) (14)
Aerodynamic Wind Tunnel 4T	4 x 4	12.5	540 to 600	Mach 0.2 to 2.0	Sea Level to 65,000	20 to 1,400	2.0 to 7.0	(6) (14)

USE LEGEND: * Testing of (1) Rockets, (2) Turbojets (3) Ramjets (4) Missile Base Heating Models, (5) Space Environmental Tests, (6) Aerodynamic Models, (7) Aerothermodynamic Models, (8) Aeroballistic Models, (9) Combined Aerodynamic Inlet and Propulsion System Tests, (10) Impact Studies, (11) Free-Jet Expansion of Rocket Exhaust Plumes, (12) Ablative Materials, (13) Ablative and Erosive Materials, (14) Store/Stage Separation

** Currently Mothballed
*** Standby Status
**** Currently Non-Operational